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Fuzzy Logic Based Load Frequency Control of Hybrid Power System Integrated with SMES

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ABSTRACT- The use of a Fuzzy logic-based controller for automatic generation control (AGC) and load frequency control (LFC) of two area power plants in an interconnected power system is proposed in this paper. In addition, a superconducting magnetic Energy Storage (SMES) unit is being considered in two areas. After a sudden load disturbance, the implementation of SMES combination arrests the initial fall in frequency deviation and tie-line power deviation. The simulation results show that the proposed SMES unit improves system performance significantly. The system's sensitivity analysis is carried out by altering the parameters and operating load conditions from their nominal values. Even when the system is subjected to wide variations in loading conditions and system parameters, the optimised gains of the proposed fuzzy logic-based controller and fuzzy controller along with SMES controllers do not need to be reset. Finally, different types of load patterns are used to test the effectiveness of the proposed controller design. The simulation results show that the Fuzzy PID controller combined with SMES outperforms the Fuzzy PID controller alone. The simulations were run using the MATLAB software.

KEYWORDS- Conventional PID controller, fuzzy PID controller, load frequency control, membership function, Inter-connected two-area system, Tie-Line power deviation.

I. INTRODUCTION

Load frequency control as being one of the key electrical power system design services, and has been employed over several decades to fulfil two significant targets, namely to maintain the variation in system frequency and tie-line power exchange interchange deviations in the stipulated levels. The basic principle of load frequency management has been discussed [1-5]. Load frequency control is widely recognized as a secondary level control as well as a prominent operation in the domain of automatic generation control (AGC). AGC is a feedback control system that adjusts the generator output power to keep the frequency specified. In a multi-area linked power system, the LFC system offers generator load control through zero steady-state errors of frequency deviations and optimum transient behavior [6]. For numerous years, load frequency control (LFC) has been employed in electric power networks as part of an automatic generation control scheme. The conventional proportional integral (PI) controller is the most widely used type of load frequency controller among the various types. The I, PI, and PID controllers are easy to implement and provide better dynamic response, however, their performance degrades as the system's complexity increases due to disturbances such as load variation. As a result, controllers capable of overcoming these challenges are required. This makes it more appropriate to use fuzzy logic-based controllers and super conducting magnetic energy storages. This research evaluates the performance of Fuzzy controller and SMES on multi area interconnected systems.

II. SYSTEM BACKGROUND

As shown in Figure 1, the system analysis is achieved on a two-area (Thermal-solar & Thermal wind) interconnected power system. This model of a power system is widely used. LFC analysis is being carried out by researchers. To further approximate the functional method, a GRC is applied to this model. The GRC is used to keep the plant's generation rate under control. For thermal power plants, the usual GRC value is 3% p.u. MW/min.

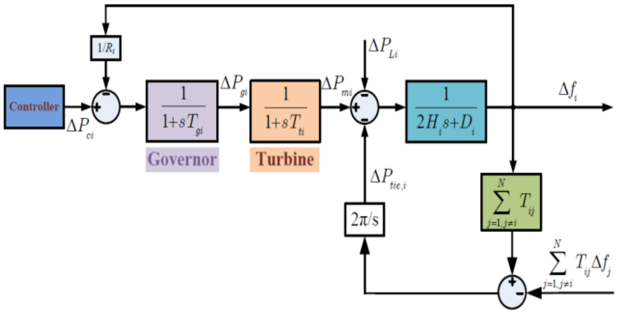


Figure 1: LFC model in an n-area power system used in [7].

The AGC's area control error (ACE) signal is a crucial part. The frequency deviation (Δf) and tie line power deviation are also included in the ACE value (ΔP_{tie}). There will be an ACE for each field. When a disturbance or load demand occurs in any field, the controller action is trigged.

$$ACE_1 = \Delta P_{tie1-2} + B_1 \Delta f_1 \qquad (1)$$
$$ACE_2 = \Delta P_{tie2-1} + B_2 \Delta f_2 \qquad (2)$$

Based on the area control error signal, the settings were fine-tuned. ($ACE_{i,\ i=1,2\ldots.}$) are the proportional gain (K_P), integral time constant (T_i), and derivative time constant (T_d). The result of the controller, u_n (n=1,2….), is written as follows.

$$u_n = K_{pn}(ACE_n + {\scriptstyle ACE_n sT_{in}} + sT_{dn}ACE_n)$$

III. FUZZY LOGIC CONTROL SYSTEMS

The theory of vagueness and uncertainty is known as fuzzy logic, or the "precise logic of imprecision and approximate reasoning [8], which, in spirit, is far closer to human thinking and, without a doubt, to natural languages than conventional logic systems [9]. This theory offers approximate yet effective techniques to describe system behaviour that may be too complex and/or undefined for accurate mathematical analyses or analysis in the form of a quantitative model [10]. So FLC may be thought of in this perspective as a set of linguistic rules linked by the twin ideas of fuzzy implication and the compositional rule of inference.

In nearly all domains of industry and science, fuzzy logic is now used. The load frequency control is one of them [11]. The basic purpose of load frequency control is to maintain a balance between production and consumption in interconnected power networks. Traditional control methods may not provide satisfactory solutions due to the complexity and multi-variable characteristics of the power system. Fuzzy controllers, on the other hand, are beneficial in handling a wide range of control issues due to their robustness and reliability [11]. Figure 2 depicts the fuzzy controller for single input, single output systems.

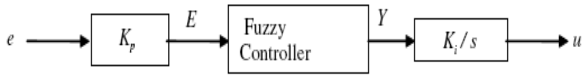


figure 2: The simple fuzzy controller

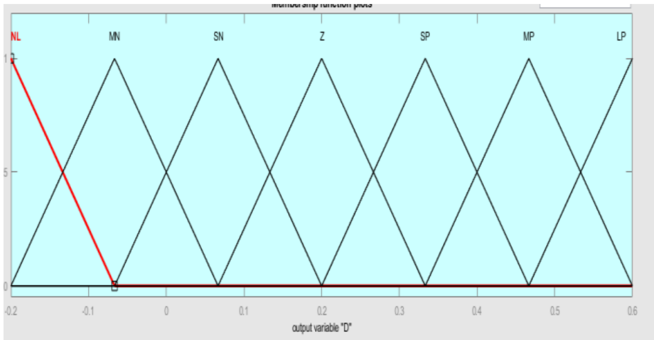
The proportional and integral gains, K_p and K_i, are shown in this diagram. The derivative of e, together with the signal E, can be used as the fuzzy controller input. Fuzzification of E, the inference mechanism, and defuzzification combine to generate the fuzzy controller block. As a result, Y is a crisp value, and u is a system control signal.

The fuzzy controller presented in this study has up to 49 rules and seven membership functions: negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), and positive big (PB). The appropriate rules are given in Table 1.

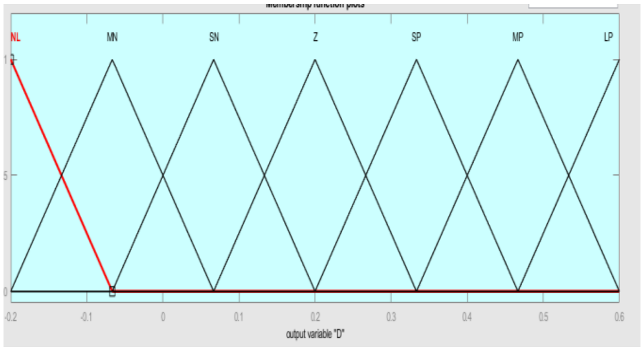
Table 1: Rule base for fuzzy controller

ACE	**dACE**						
	LN	MN	SN	Z	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	Z
MN	LP	MP	MP	MP	SP	Z	SN
SN	LP	MP	SP	SP	Z	SN	MN
Z	MP	MP	SP	Z	SN	MN	MN
SP	MP	SP	Z	SN	SN	MN	NL
MP	SP	Z	SN	MN	MN	MN	NL
LP	Z	SN	MN	MN	NL	NL	NL

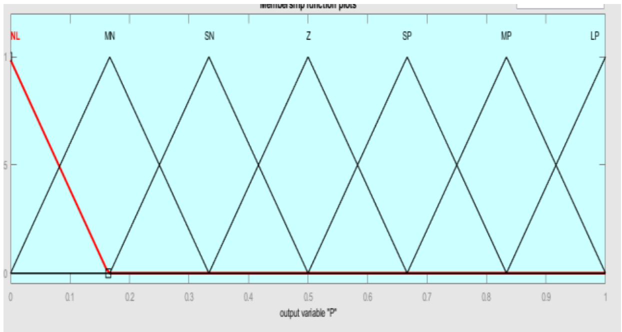
The Mamdani fuzzy inference engine was chosen and implemented using triangular membership for proportion, integral, and derivative controllers for semantic variables (K_p, K_i, K_d ,ACE,dACE).



(a)



(b)



(c)

figure 3: Membership function of Fuzzy PID controller of a) ACE b) dACE c) $K\,p$, $K\,i$ and $K\,d$

IV. ANALYSIS OF SMES AND ITS CONTROL STRATEGY

SMES (Super Conducting Magnetic Energy Storage) is a device that can store electrical energy from the grid in a coil's magnetic field. The coil's magnetic field is made of superconducting wire, which has a near-zero energy loss. SMES has the ability to store and refurbish large amounts of energy almost instantly. To avoid a rapid loss in line power, the power system can discharge high levels of power in a fraction of a cycle. The SMES device is made up of an inductor-converter unit, a dc superconducting inductor, an AC/DC converter, and a step-down transformer. Because all parts of a SMES unit are static, the device's stability is superior to that of other power storage devices.

The utility grid will charge the superconducting coil to a level that is normally less than the maximum charge. A power conversion system, which includes an inverter and rectifier, connects the DC magnetic coil to the AC grid. The superconducting coil conducts current after being charged, which creates an electromagnetic field with almost no losses. The coil is maintained at a very low temperature. When there is a sudden increase in load demand, the stored energy in the super conducting coil is released to the electrical network in the form of AC via the power conversion system (PCS) [12-14].

V. RESULT DISCUSSION

A. Frequency and Tie Line Power Response

The frequency response with respect to time of two area interconnected power system with Fuzzy-I. Fuzzy PI and Fuzzy PID controllers are plotted.

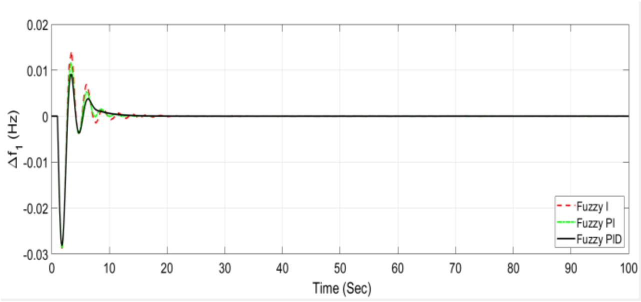


Figure 4: Frequency Deviation in area 1 (Pu Hz)

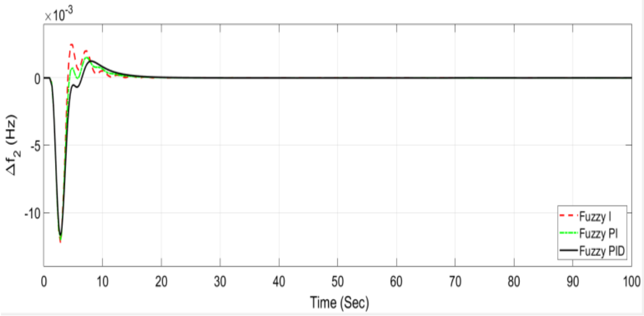


Figure 5: Frequency Deviation in area 2 (Pu Hz)

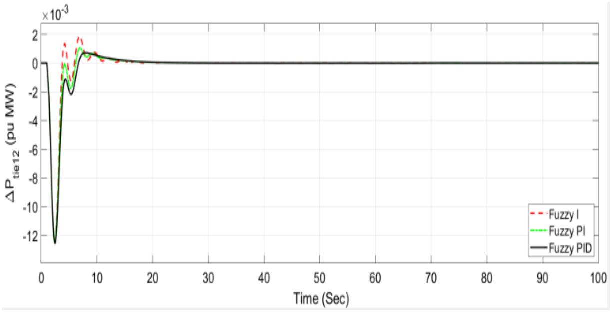


Figure 6: Tie-Line Power Deviation in areas (Pu MW)

B. Frequency And Tie Line Power Response With Smes

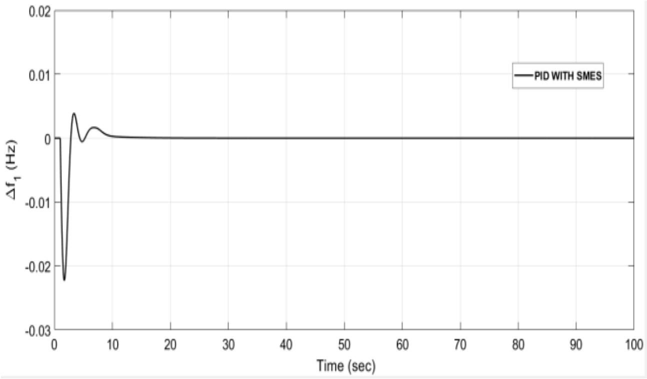


Figure 7: Frequency Deviation in area 1with SMES unit

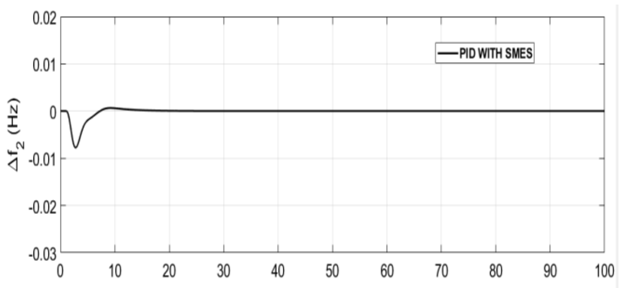


Figure 8: Frequency Deviation in area 2 with SMES Unit

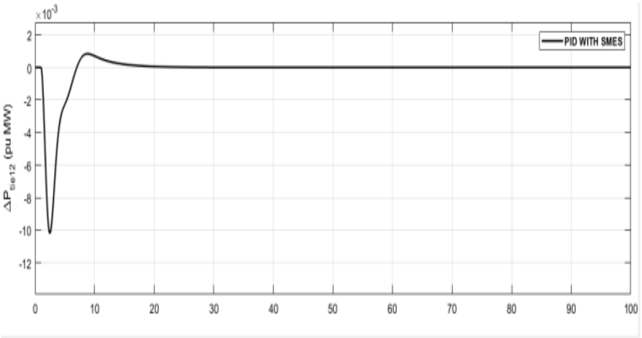


Figure 9: Tie-Line Power Deviation In areas with SMES unit

C. *Comparison Of Frequency And Tie-Line Power Response Of Fuzzy Pid And Smes*

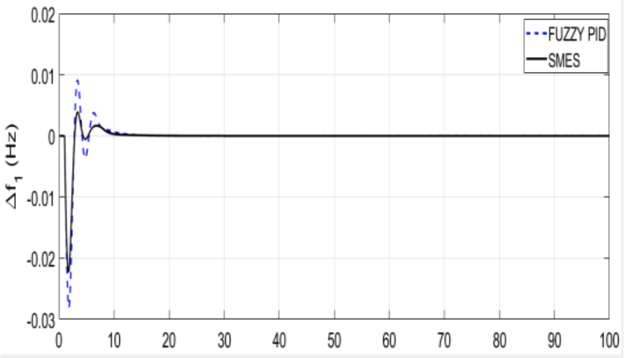


Figure 10: Comparison of Frequency Deviation in area 1

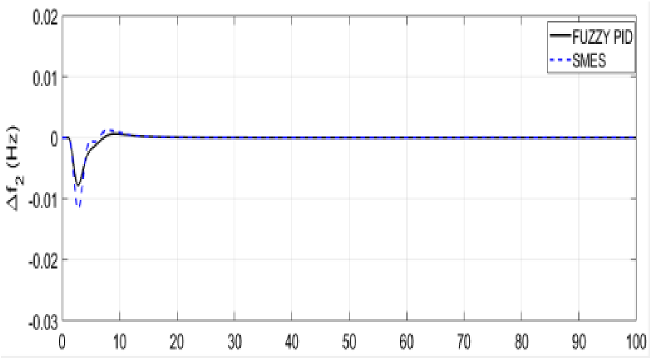


Fig 11: Comparison of Frequency Deviation in area 2

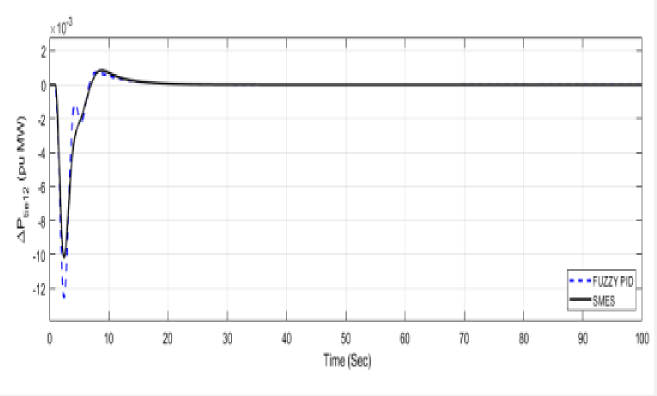


Figure 12**:** Comparison of Tie-Line Power Deviation in areas

D. *Controllers And Parameters Table For Results Discussion*

Table 2: Performance Analysis of Frequency Response for Area 1

S.No.	**Parameter**	**Fuzzy I**	**Fuzzy PI**	**Fuzzy PID**
1	Peak Undershoot (Hz)	-0.02782	-0.02856	-0.0277
2	Peak Overshoot (Hz)	0.014178	0.01176	0.009082
3	Settling Time (Sec)	35	25	20

Table 3: Performance Analysis of Frequency Response for Area 2

S.No.	Parameter	Fuzzy I	Fuzzy PI	Fuzzy PID
1	Peak Undershoot (Hz)	-0.02782	-0.02856	-0.0277
2	Peak Overshoot (Hz)	0.014178	0.01176	0.009082
3	Settling Time (Sec)	35	25	20

Table 4: Performance Analysis of Tie Line Power in areas

S.No	Parameter	Fuzzy I	Fuzzy PI	Fuzzy PID
1	Peak Undershoot (Hz)	-0.0279	-0.02840	-0.002
2	Peak Overshoot (Hz)	0.002463	0.001537	0.001247
3	Settling Time (Sec)	35	25	20

Table 5: Performance Analysis of frequency Deviation in area 1with SMES

S.No	Parameter	Fuzzy PID	Fuzzy PID with SMES
1	Peak undershoot (Hz)	-0.02806	-0.02207
2	Peak overshoot (Hz)	0.009082	0.00391
3	Settling Time (Sec)	20	14

Table 6: Performance Analysis of frequency Deviation in area 2 with SMES

S.No	Parameter	Fuzzy PID	Fuzzy PID with SMES
1	Peak undershoot (Hz)	-0.01161	-0.007713
2	Peak overshoot (Hz)	0.001247	0.000645
3	Settling Time (Sec)	20	14

Table 7. Performance Analysis of Tie-Line Power

S.No	Parameter	Fuzzy PID	Fuzzy PID with SMES
1	Peak undershoot (Hz)	-0.01257	-0.0102
2	Peak overshoot (Hz)	0.0007026	0.0006681
3	Settling Time (Sec)	20	14

VI. CONCLUSION

Fuzzy-PID logic and fuzzy PID controllers with SMES were used to investigate two area systems. This study aims to contribute to the development of an intelligent, fast, and improved load frequency control (LFC) controller for nonlinear linked power systems. In summary, considerable gains in dynamic responses are found when Fuzzy-PID logic and fuzzy PID controllers are used in conjunction with SMES. In addition, the SMES unit is included in the system model to increase system performance. The dynamic performance of the system is improved when the SMES unit is placed with the load line. The impact of SMES on the AGC is then investigated. With coordinated application of SMES, significant improvements in dynamic responses are produced, according to simulation data. Finally, a sensitivity analysis is performed to demonstrate the controller's robustness by altering the loading circumstances and system parameters by 1% to 2% from their nominal values. When compared to existing controllers, simulation results show that the suggested controller performed well against random load patterns when combined with SMES.

APPENDIX

Table 8**:** Parameter of the system and their nominal values [5]

Parameter Values	**Symbol**	**Values**
Hydraulic time constant	T_H	0.08 SEC
Turbine Time constant	T_T	0.3 sec
Reheat time constant	T_R	10.0 SEC
Reheat gain	K_R	0.5
Control area time Constant	T_P	20 SEC
Control area gain	K_P	120
Regulation constant	R	2.4 Hz/MW
Frequency bias constant	B	0.425MW/Hz
Synchronization time constant	T_{12}	0.086

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